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FLIGHT TESTS FOR PROTOTYPE FELT WEDGE/WHITE PHOSPHOROUS IMPROVED SMOKE CONCEPT

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April 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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Four 155mm prototype felt-wedge/phosphorous payload projectiles were tested for flight stability at Charge 4 from an M109A1 weapon. A simulant for liquid white phosphorous was used during this test conducted at Aberdeen Proving Ground, MD. Launch disturbances up to 12.5 degrees were induced. The four projectiles were stable.

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I. INTRODUCTION

Projectiles with a payload of felt wedges impregnated with a liquid white phosphorous (WP) simulant were tested successfully for flight stability at Charge 4 (see Figure 1). The payload consisted of four stacks of 90-degree wedges, 23 wedges per stack. Approximately 5.5 kg of simulant was absorbed by the felt. The felt wedge payload was inserted into a canister and used on projectile of design similar to the 155mm XM761 wick projectile. Yaw levels between 7 and 12.5 degrees were induced on a four round group of projectiles, and all projectiles were stable. The projectile hardware was fabricated by the Chemical Systems Laboratory (CSL), Edgewood Area; an M109A1 weapon with crew was provided by the Material Test Directorate, TECOM; yawsonde instrumentation, a ground receiving station, and a muzzle chronograph were supplied and operated by the BRL. Based on this initial test and data from a spin fixture built by the Weapons Systems Concepts Team (WSCT-EA)*, Edgewood Area, the felt wedge concept is a viable submunition design for a WP improved smoke projectile.

II. BACKGROUND

The XM761 projectile is shown in Figure 2. This projectile was the first concept for improved smoke obscuration from a 155mm projectile. It employed a WP/cotton wick concept, but flight instabilities resulted when the WP was liquid[1,2,3]. Development of the XM761 was terminated, but the BRL initiated a diagnostic program to determine the mechanism of the wick instability[4]; and the WSCT-EA has built a spin fixture to test various payload concepts for the presence of a large despin moment (of the type exhibited by wick projectiles). The first phase of the BRL diagnostic program tested hardware similar to the original XM761, but addressed the use of a blended Freon simulant for liquid WP and the importance of a liquid-free surface on wick-type instabilities. It was determined that the Freon simulant reproduced the wick instability and

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1. *W. P. D'Amico, "Early Flight Experiences with the XM761," Ballistic Research Laboratory Memorandum Report No. 2791, September 1977.* (AD #B024975L)
2. *W. P. D'Amico, "Field Tests of the XM761: First Diagnostic Test," Ballistic Research Laboratory Memorandum Report No. 2792, September 1977.* (AD #B024976L)
3. *W. P. D'Amico, "Field Tests of the XM761: Second Diagnostic Test," Ballistic Research Laboratory Memorandum Report in preparation.*
4. *W. P. D'Amico, "Diagnostic Tests for Wick-Type Payloads - Phase I," Ballistic Research Laboratory Memorandum Report in publication.*

**Contact Mr. Miles Miller.*

that fill ratios of 100% did not eliminate the wick instability. Similar conclusions had been reached on the WSCT-EA spin fixture.

As a result of spin fixture tests, two additional WP improved-smoke concepts have been flight tested by the BRL. One concept was the pentamerous (PENT) design which utilized a solid metal cylinder with 18 longitudinal core holes. A wick was placed into each hole. Three decks were assembled in a single canister and loaded into an M687 projectile body. Approximately 5 kg of liquid payload can be loaded into this configuration. Three pentamerous projectiles were tested during the BRL diagnostic program and were launched with approximately 15 degrees of initial yaw. All three projectiles were unstable and exhibited a strong coupling between the spin and yaw of the projectile. In order to provide baseline data for testing the felt-wedge concept, a pentamerous projectile and an XM761 MOD 1D projectile were saved from the BRL diagnostic program and fired during the same test sequence as the four felt-wedge projectiles. Both wick-type projectiles exhibited unstable behavior and detailed data plots are provided in Section III.

III. TEST PROGRAM

Instrumentation for the felt-wedge test was held to a minimum, with primary reliance placed on the BRL-built yawsondes[5]. A yaw inducer similar to the type described in Reference 1 was employed with a side-plate height of 7 cm. Tracking radar and down-range observers were not employed. The program was conducted from a firing position near Mulberry Point (New Barricade) with an azimuth of 53° West of South. Firings were held on two days, 1 and 15 November.

Test conditions on 1 November were not optimum, but an attempt to obtain yawsonde data was requested by CSL. Raw data were received and indicated stable flights with initial launch yaws of approximately 7 degrees, but no reduced data are presented since the quality of the raw data was quite poor. Good test conditions existed on 15 November and good data were obtained. The yawsonde data within this report were produced by a portable processor and a Hewlett Packard 9830 calculator and plotter. This is a system built by the BRL. Yawsonde data are presented in the form of solar angle and spin. Sigma N is the complement of the solar angle, which is the angle between a vector drawn to the sun and the spin axis of the projectile. Spin data are actually in the form of the derivative of the Eulerian roll angle of the projectile but are simply labeled "spin" within this report. Oscillations are superimposed upon the spin history when the associated yawing motion is large, and methods

5. *W. H. Mermagen and W. H. Clay, "The Design of a Second Generation Yawsonde," Ballistic Research Laboratories Memorandum Report No. 2368, April 1974. AD 780064.*

are available to reduce the amplitude of these oscillations[6]. The methods of Reference 6 were not applied to the data within this report, however. Table 1 lists a round-by-round summary of the firing program, while Table 2 lists the physical characteristics of the projectiles tested.

Round 1042, a pentamerous concept, was launched with an initial disturbance of 10 degrees. The solar angle data show that by 4 seconds the motion was rapidly growing and substantial losses in spin occurred (Figures 3 and 4). Round 1043 was a felt-wedge concept projectile and was launched with an initial yaw of 9.5 degrees. The resulting angular motion was quite typical for M483A1-type projectiles, and a precessionally dominated limit cycle characterized the flight history (Figure 5). Figure 6 shows the associated spin data to be quite normal. Round 1044, also a felt-wedge concept projectile, was launched with an initial yaw of 12.5 degrees, and the resulting motion although stable was not identical to Round 1043. The nutational component of yaw induced at launch persisted for almost 8 seconds of flight before giving way to the expected precessional limit cycle. Both rounds were stable, however. The final round tested was an XM761 MOD 1D. This projectile, Round 1041, contained 48 wicks and was filled to 90% of the available canister volume. Figure 9 shows an initial launch disturbance of 11 degrees and unstable behavior is precipitated within 2 seconds of launch. A rapid decrease in spin was also recorded, as Figure 10 indicates.

IV. DISCUSSION

The results of this test indicate that a felt-wedge concept has substantially better flight performance than previously investigated wick concepts. Launches at Charge 4 were selected because of a substantial experience with the wick projectiles at Charge 4 and because of range restrictions. The behavior exhibited by Round 1044, however, should be carefully investigated. This type of rapid precessional damping and slower nutational damping has been observed on other projectile types (Figure 11), but the lack of rapid nutational damping may be caused by the liquid/felt payload. For example, yawsonde data for an XM761 projectile reported in Reference 3 is shown in Figure 12. This projectile was stable, but sluggish nutational damping characterized the flight history and for larger levels of initial yaw unstable flights resulted. Also within Reference 4, natural launch Charge 6 conditions produced dramatic instabilities for wick-type projectiles (Figure 13). Thus, tests should be undertaken with felt payloads at high charges to determine projectile stability.

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6. *C. H. Murphy, "Effect of Large High-Frequency Angular Motion of a Shell on the Analysis of Its Yawsonde Records," Ballistic Research Laboratories Memorandum Report No. 2581, February 1976. AD B0094210.*

The strongest reason for a careful ballistic examination of the felt concept is that the mechanism of how the felt wedges avoid the wick-type instability is not understood. Except for a realization that the felt is a closely packed, random fiber matrix, neither a physical or computational model is available and at present only empirical evidence indicates that a stable payload configuration has been found. It is not necessarily the case, however, that the felt wedge concept would be as untractable to analytical methods as the wick concept was. The felt wedges could be represented by a porous media that fills the interior of a cylinder. The details of the x-rib could be omitted in an attempt to isolate important physical parameters. Flow through porous media is a subject of interest in many fields of engineering and science, e.g., ground water hydrology, geophysics, and chemical processes. An excellent introduction to this subject was authored by Bear[7]. Also, highly permeable media have been used to achieve substantial reductions in the time to liquid spin-up for liquid-filled projectiles, and a patent has been awarded for such a process.[8]

V. CONCLUSION

A felt-wedge concept was tested with a WP liquid simulant under the conditions of yaw induction at Charge 4. A substantial increase in flight stability has been achieved at Charge 4 over any other WP submunition concept. Carefully designed ballistic trials should, however, be designed to preclude any unforseen flight instabilities since an analytical representation of this payload concept is not yet available. The data base that has been established should provide the impetus for continued development of this smoke concept.

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7. *Jacob Bear, Dynamics of Fluids in Porous Media, New York, London, Amsterdam, American Elsevier Publishing Company, Inc., 1972.*

8. *W. P. D'Amico, "The Application of a Highly Permeable Media to Reduce Spin-Up Time and to Stabilize a Liquid-Filled Shell," Ballistic Research Laboratory Memorandum Report in publication.*

Table 1. Round-by-Round Summary

BRL Number	Ogive Number	Projectile Type	Muzzle Velocity (m/s)	Quadrant Elevation (deg)	Comments
1038	277	Felt	307.7	15	Stable
1039	278	Felt	327.9	15	Stable
1042	Sm 4	Pentamerous	328.1	30	Unstable
1043	279	Felt	332.3	30	Stable
1044	280	Felt	327.0	30	Stable
1041	Sm 14	XM761 MOD 1D	323.9	30	Unstable

Table 2. Projectile Physical Characteristics

BRL Number	Weight kg	CG (m)	Moment of Inertia Axial ($kg \cdot m^2$)	Moment of Inertia Transverse ($kg \cdot m^2$)
1038	48.09	0.326	0.1740	1.850
1039	48.21	0.324	0.1745	1.855
1042	45.89	0.324	0.1699	1.793
1043	48.19	0.324	0.1741	1.855
1044	47.93	0.325	0.1731	1.848
1041	42.54	0.330	0.1685	1.704

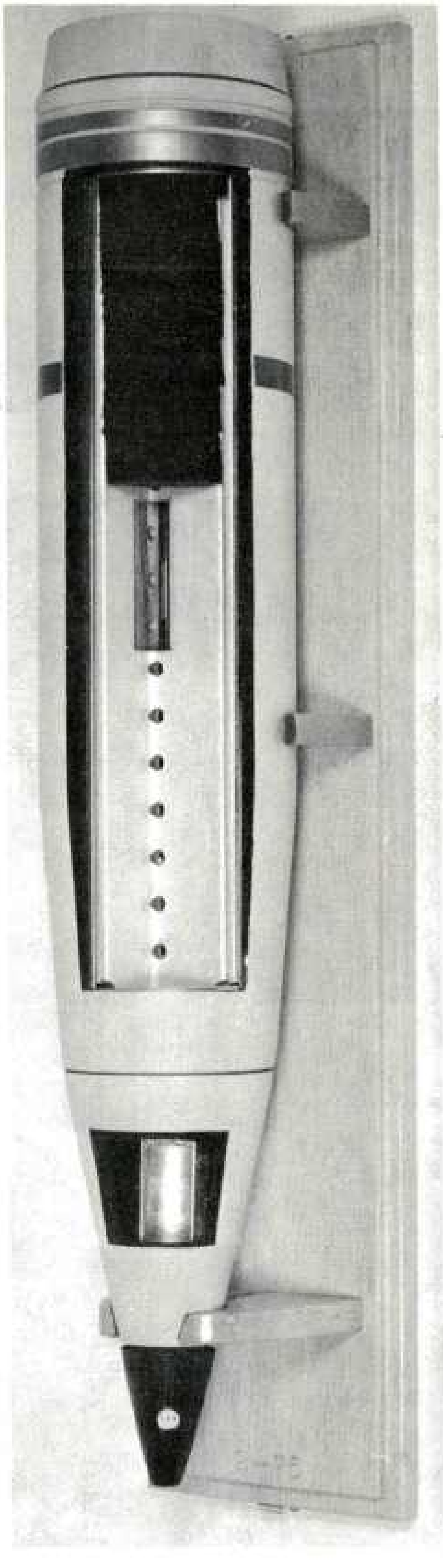

Figure 1. Felt Wedge Concept

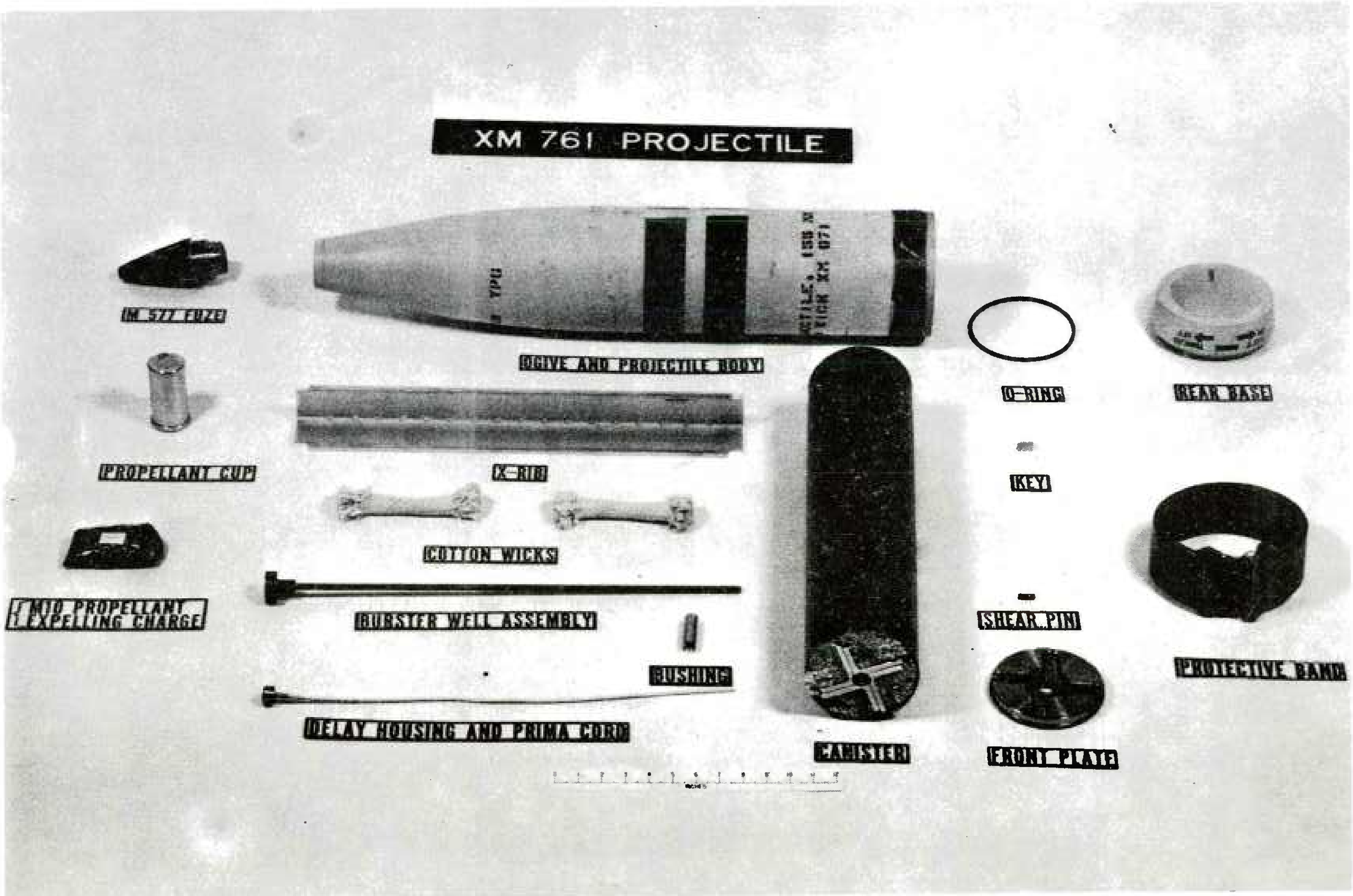

Figure 2. XM761 Projectile Assembly

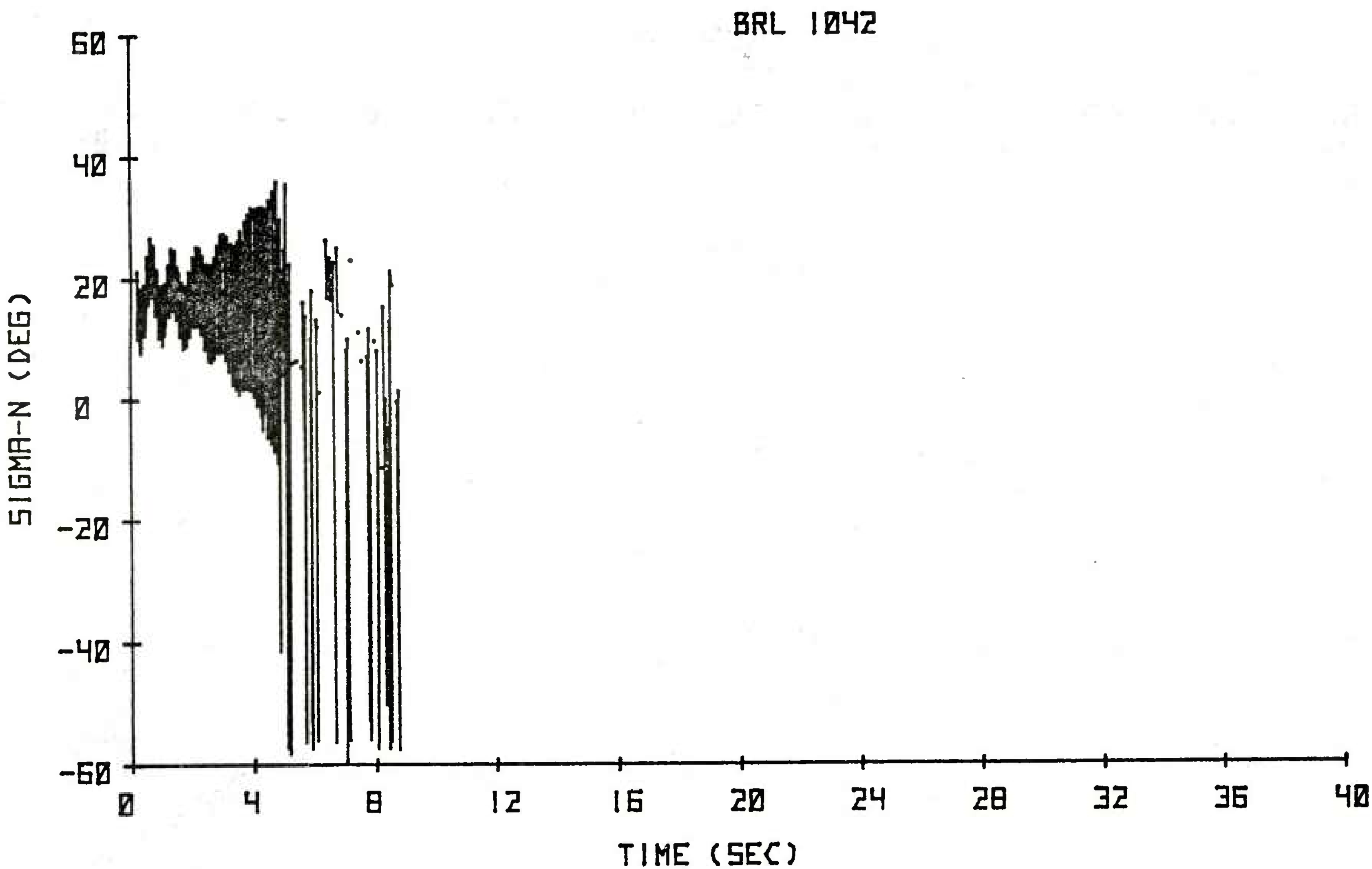

Figure 3. Sigma N Versus Time - BRL 1042, XM 761 PENT

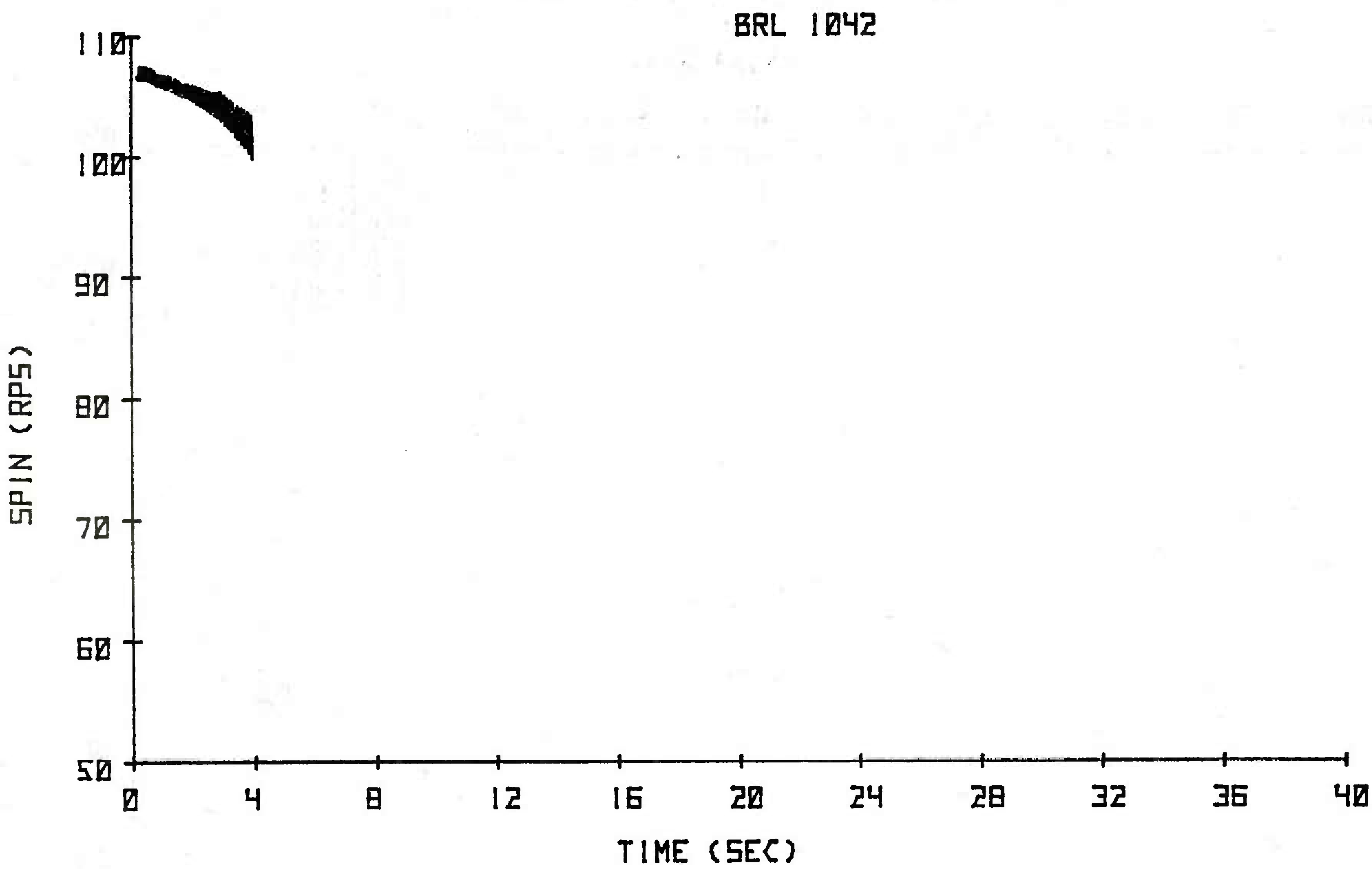

Figure 4. Spin Versus Time - BRL 1042, XM761 PENT

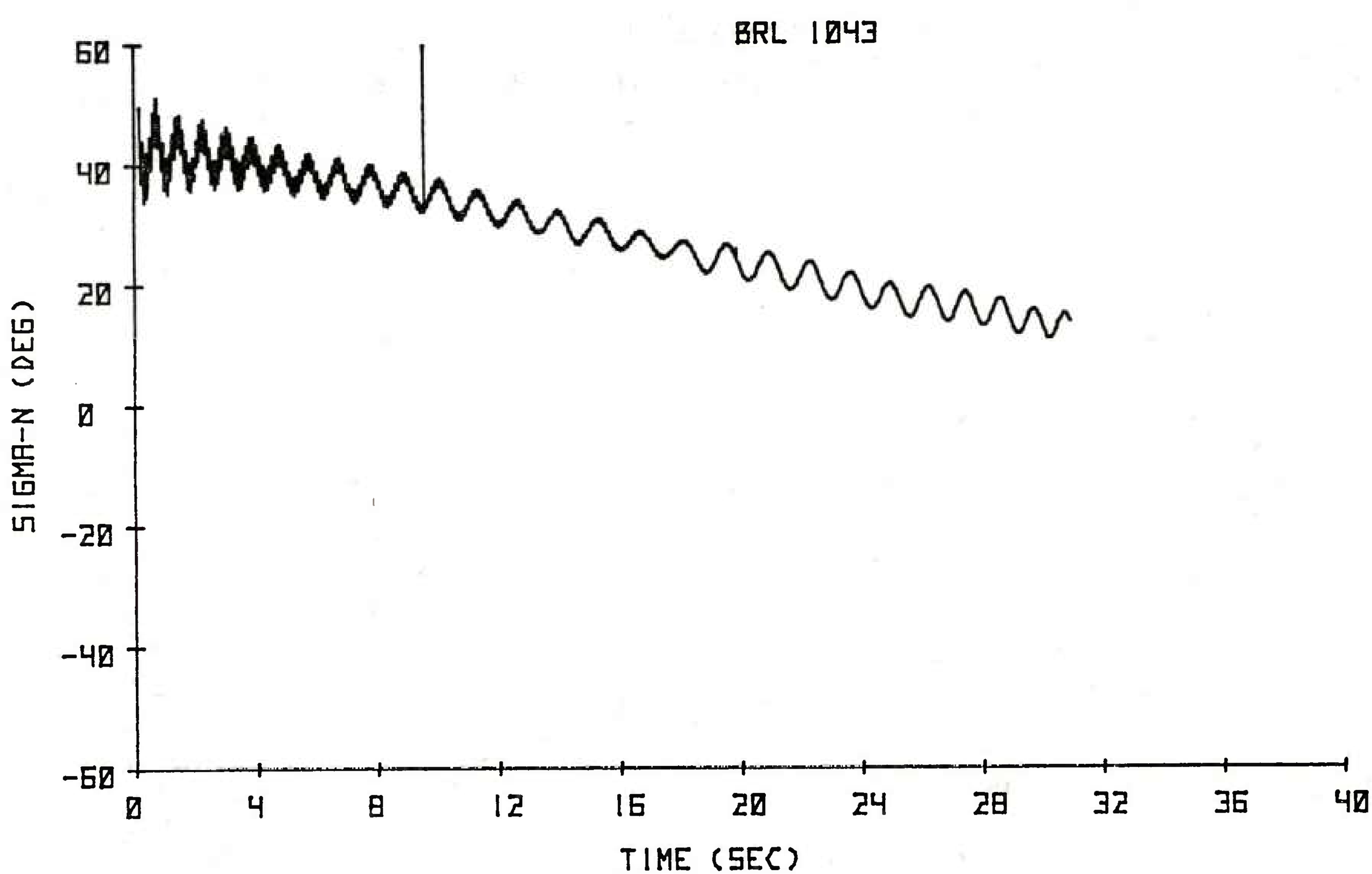

Figure 5. Sigma N Versus Time - BRL 1043, FELT WEDGE CONCEPT

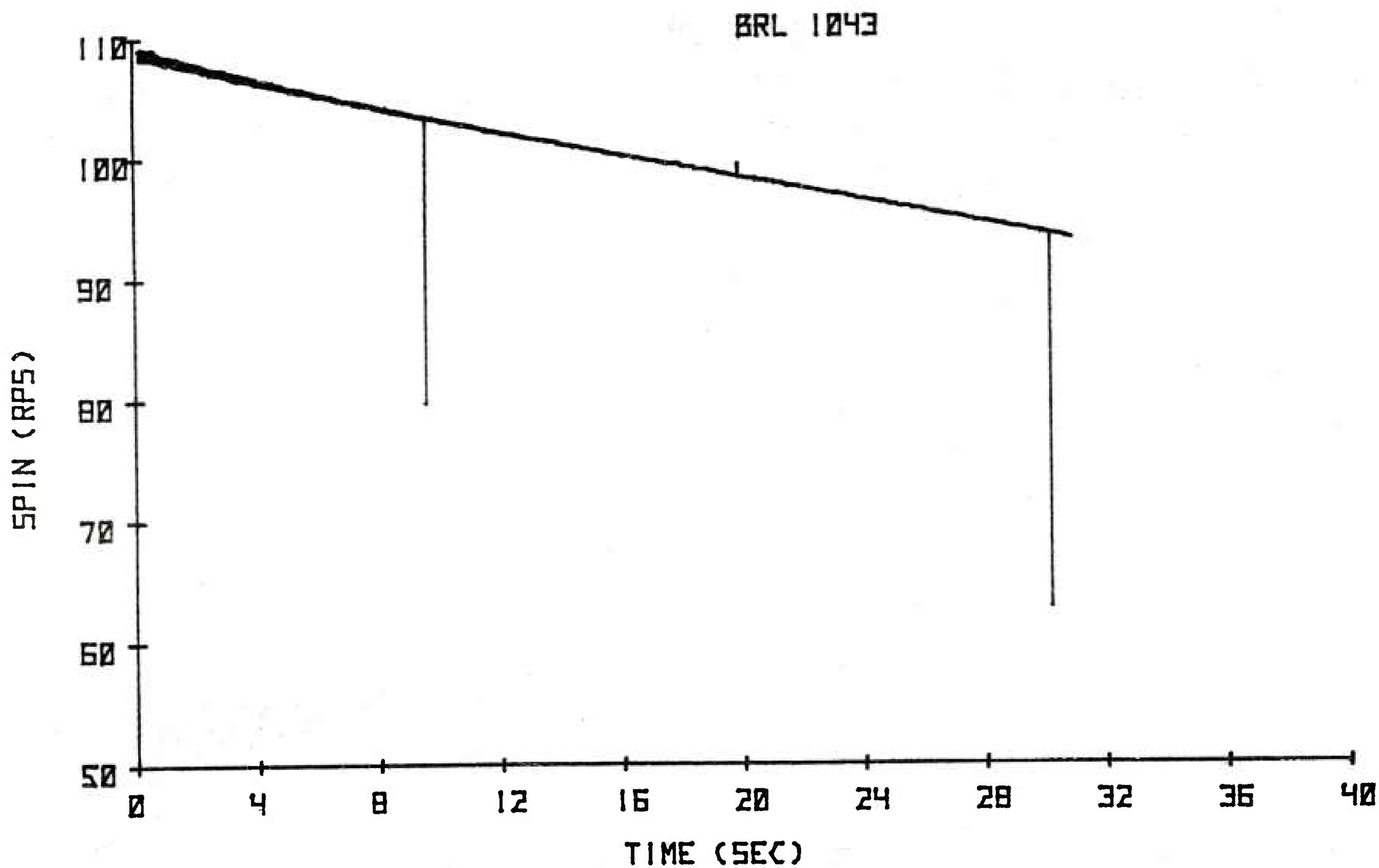

Figure 6. Spin Versus Time - BRL 1043, FELT WEDGE CONCEPT

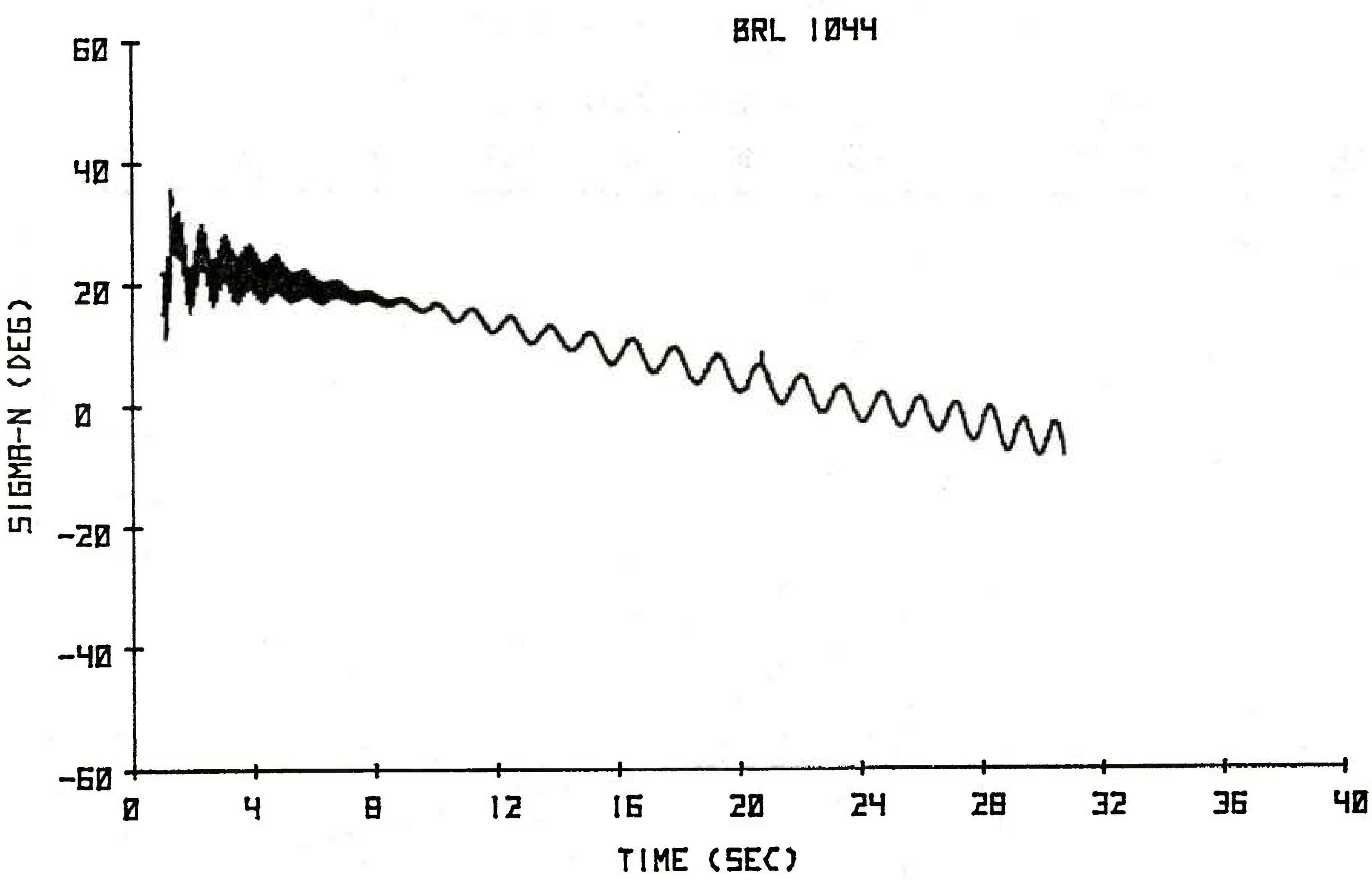

Figure 7. Sigma N Versus Time - BRL 1044, FELT WEDGE CONCEPT

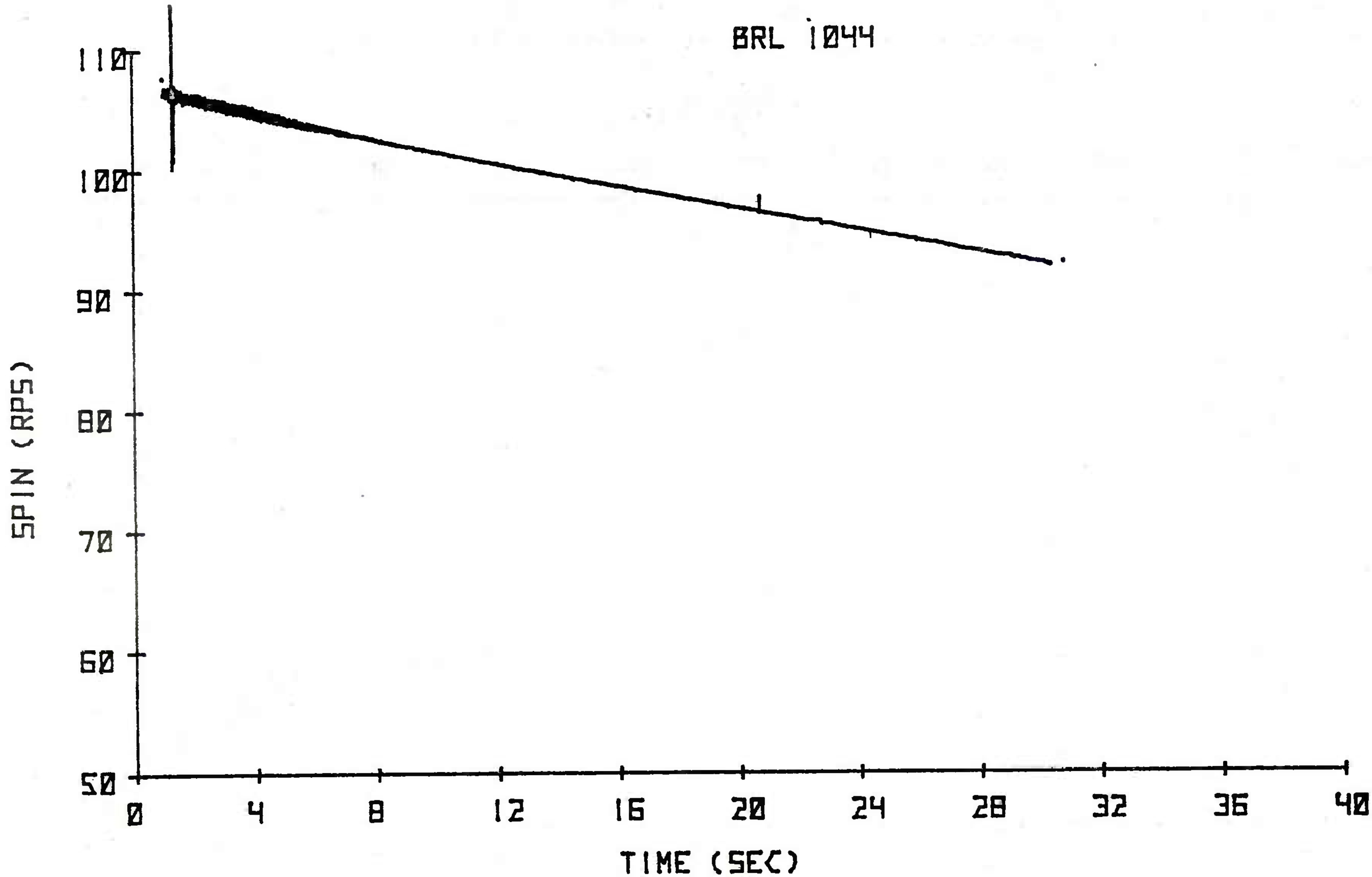

Figure 8. Spin Versus Time - BRL 1044, FELT WEDGE CONCEPT

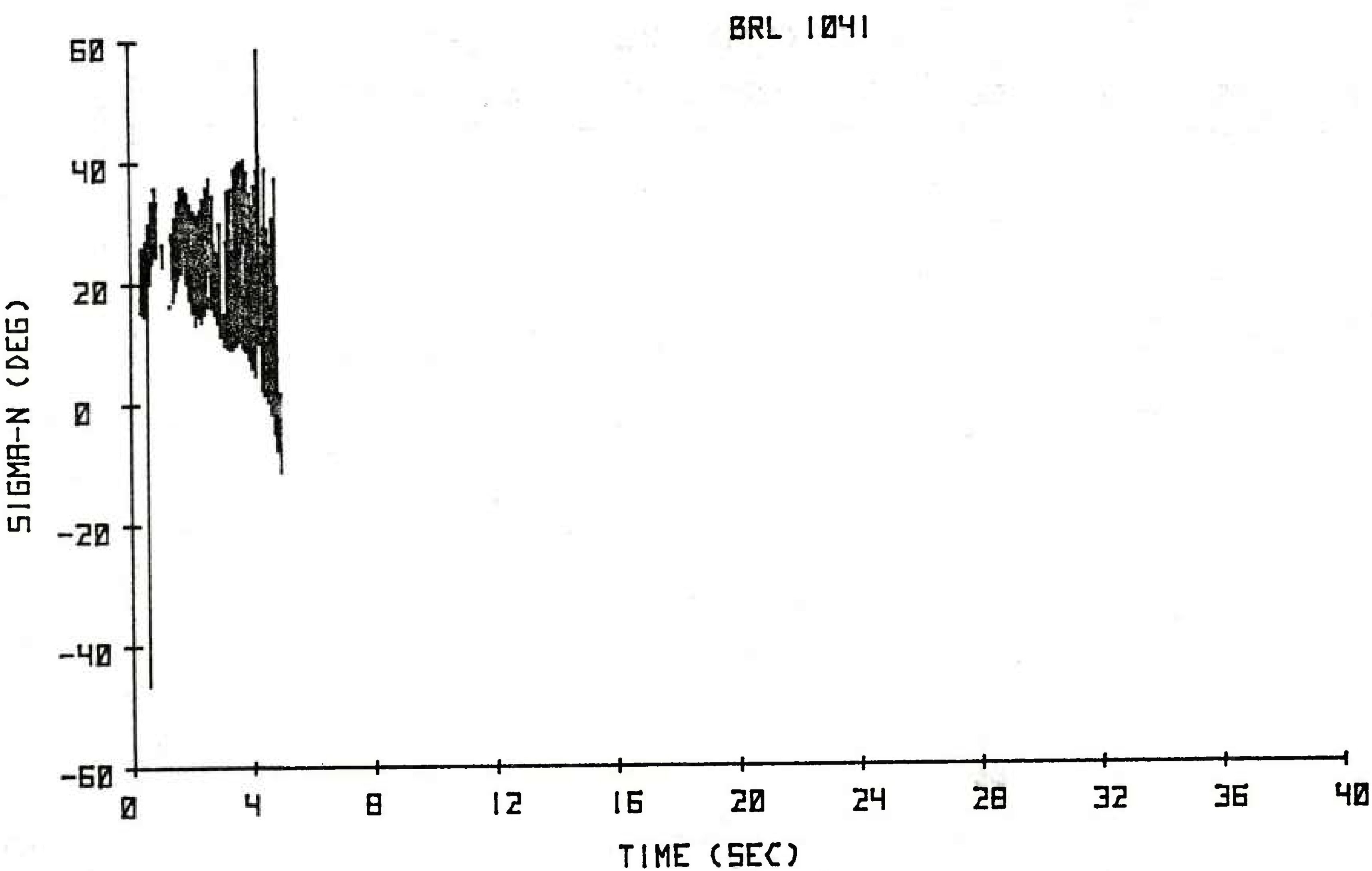

Figure 9. Sigma N Versus Time - BRL 1041, XM761 MOD 1D

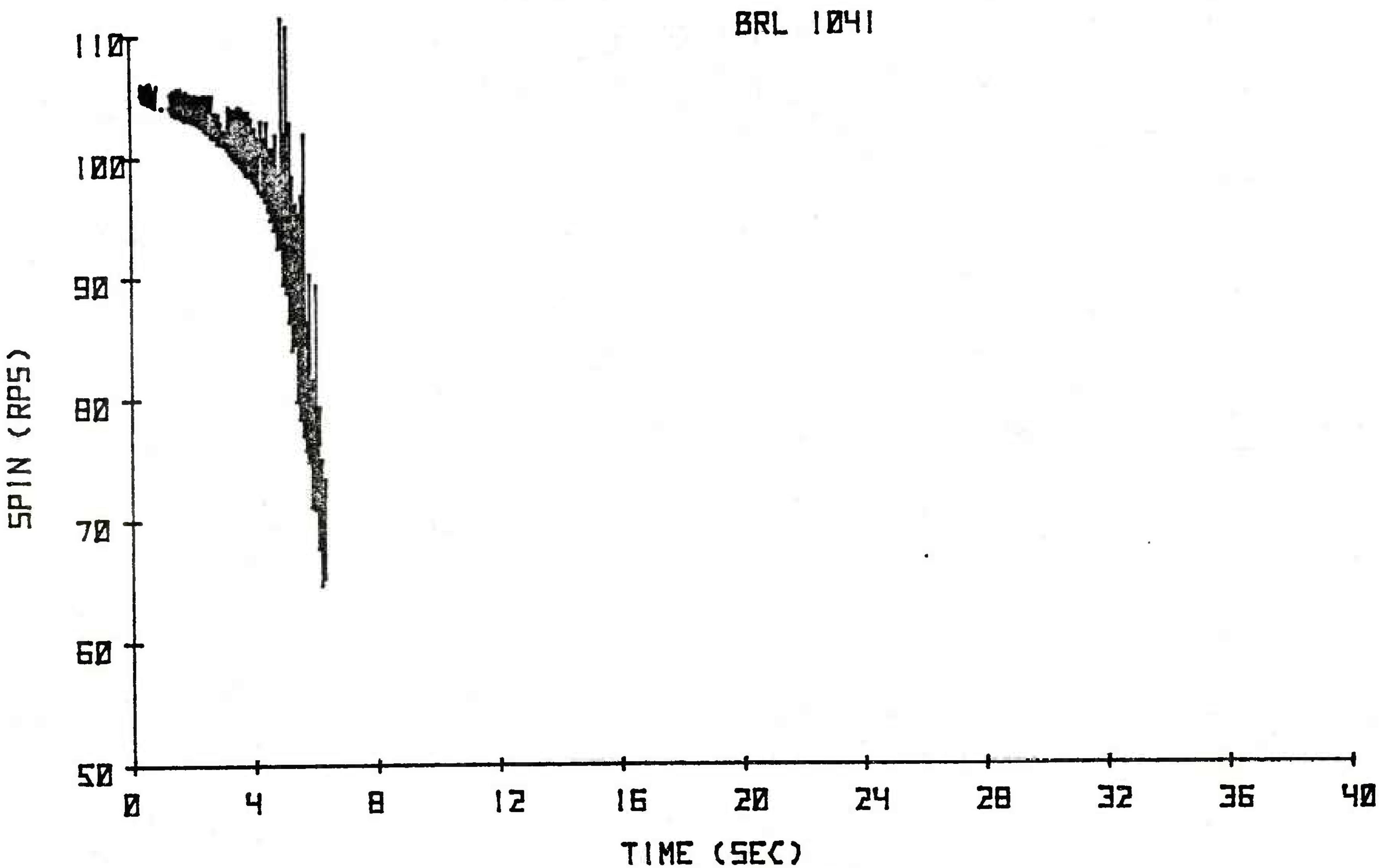

Figure 10. Spin Versus Time - BRL 1041, XM761 MOD 1D

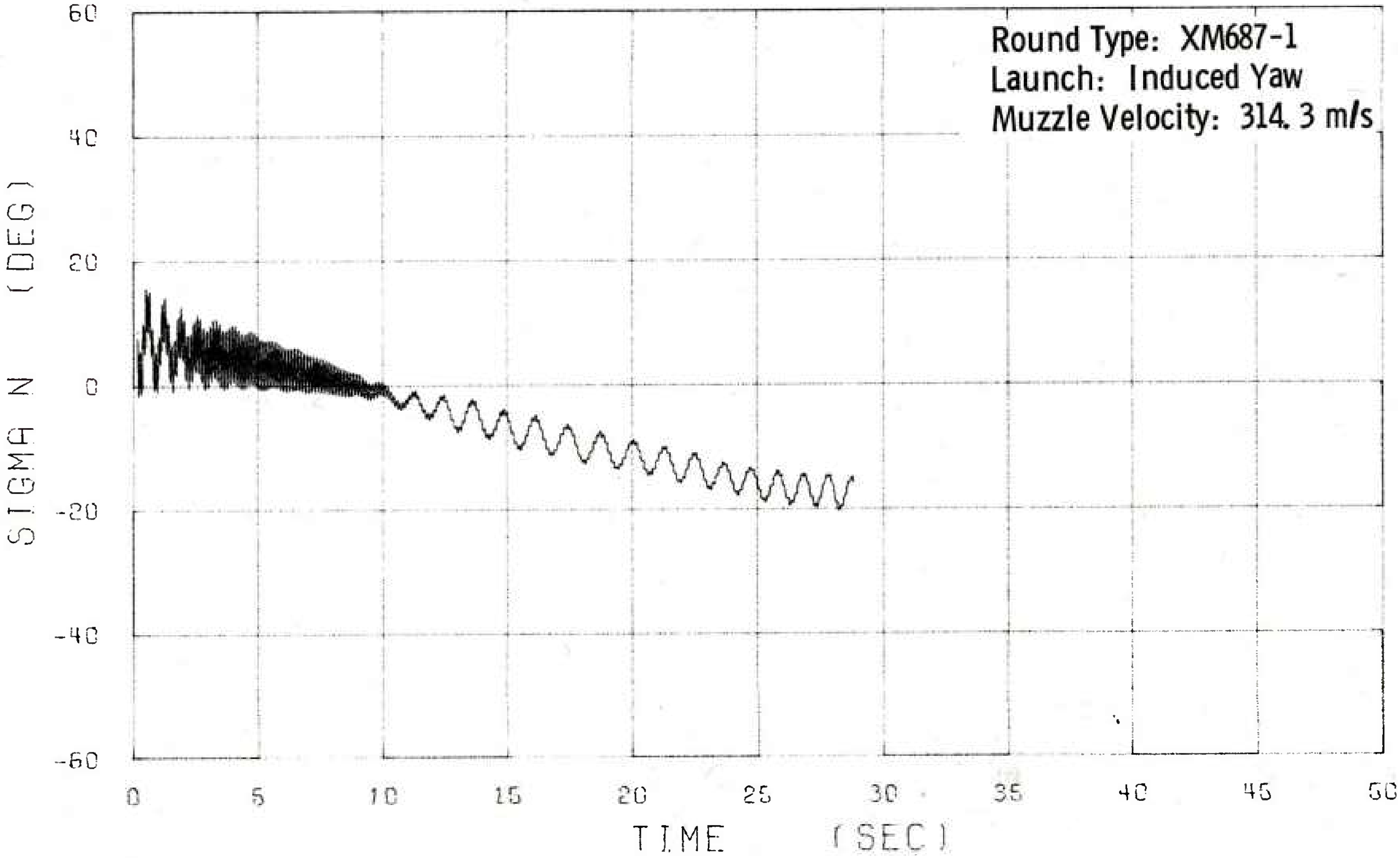

FIGURE 11. SIGMA N VS TIME ROUND NY1065

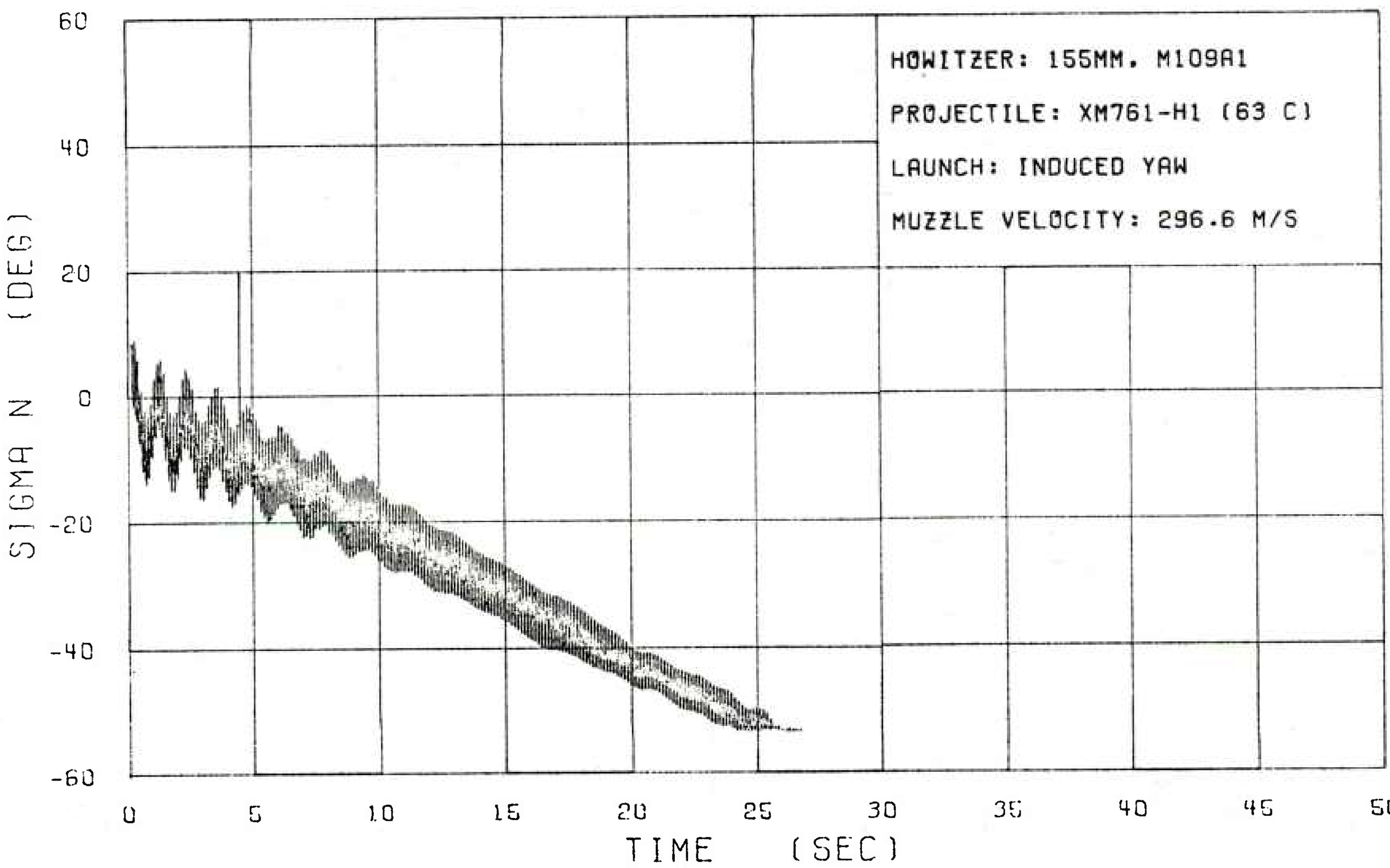

FIGURE 12. SIGMA N VS TIME ROUND 32

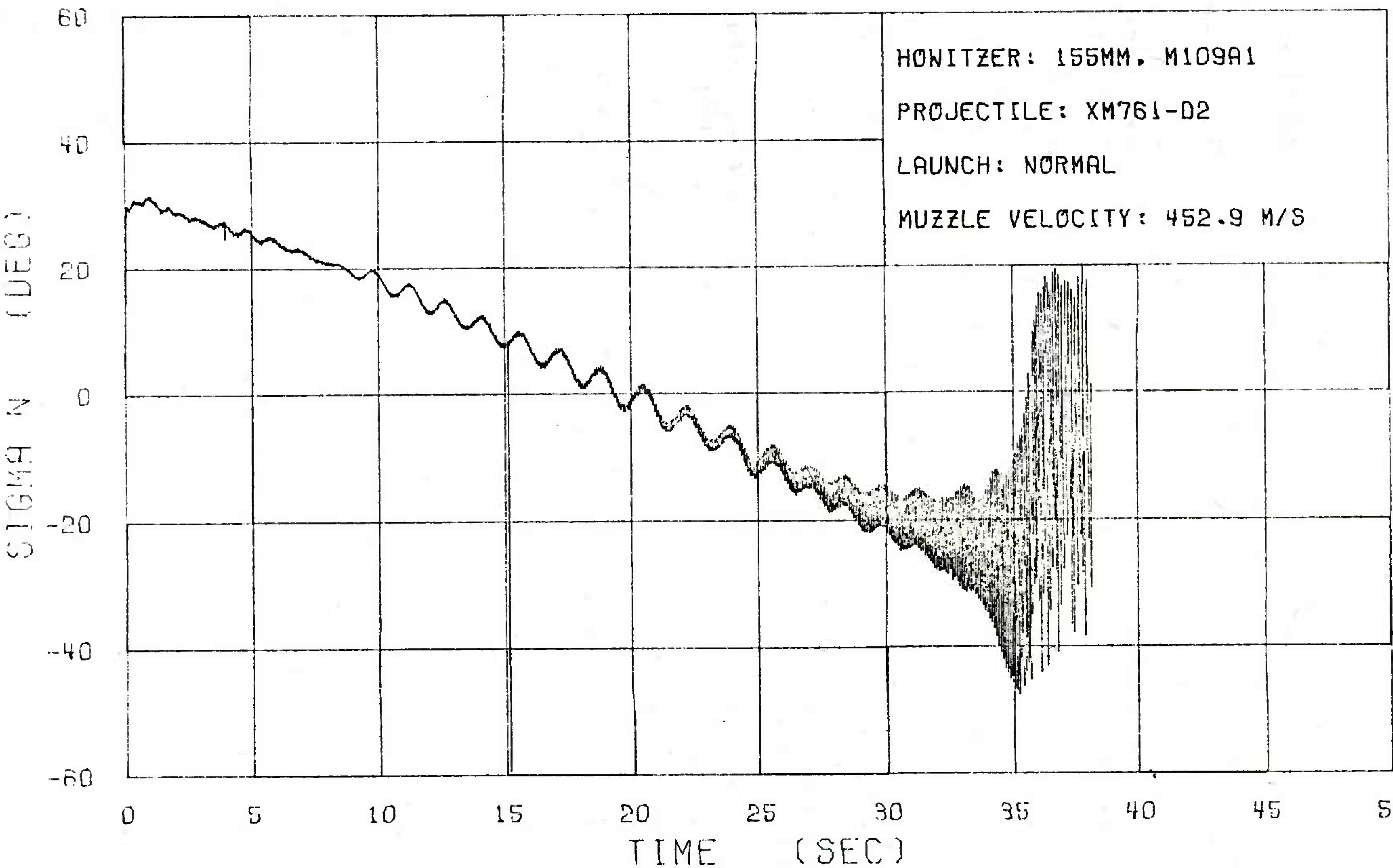

FIGURE 13. SIGMA N VS TIME ROUND 6

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7. Jacob Bear, Dynamics of Fluids in Porous Media, New York, London, Amsterdam, American Elsevier Publishing Company, Inc., 1972.
8. W. P. D'Amico, "The Application of a Highly Permeable Media to Reduce Spin-Up Time and to Stabilize a Liquid-Filled Shell," Ballistic Research Laboratory Memorandum Report in publication.

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